

Substrates with a self-cleaning surface, a process for their production and their use**Description**

The invention relates to a substrate with at least one self-cleaning surface, the substrates being in particular a substrate of glass, ceramic, plastic or metal or a glazed or enamelled substrate. The self-cleaning surface located on the substrate is based on a coating with structure-forming particles which is located on the substrate, resulting in a surface structure of elevations and depressions; the surface is at least partly hydrophobic. The invention also relates to a composition for the production of a substrate according to the invention with at least one self-cleaning surface. The invention also relates to a process for the production of the substrate with at least one self-cleaning surface, which comprises coating the substrate with the abovementioned composition. Finally, the invention also relates to the use of the substrates according to the invention with a self-cleaning surface.

It is known that to achieve a good self-cleaning effect on a surface, in addition to a good hydrophobicity this must also have a micro-rough surface structure. Both features are realized in nature, for example in the lotus leaf; the surface form from a hydrophobic material has pyramid-shaped elevations a few μm from one another. Drops of water come into contact substantially only with these peaks, so that the contact area is minuscule, resulting in a very low adhesion. These relationships and the main applicability of the "lotus effect" to technical surfaces are the doctrine of A.A. Abramzon, Khimia i Zhizu (1982), no. 11, 38-40.

Without reference to the lotus effect, US 3, 354,022 discloses water-repellent surfaces, the surface having a micro-rough structure with elevations and depressions and being formed from a hydrophobic material, in particular a fluorine-containing polymer. According to one embodiment, a surface with a self-cleaning effect can be applied to ceramic brick or to glass by coating the substrate with a suspension which comprises glass beads with a diameter in the range from 3 to 12 μm and a fluorocarbon wax based on a fluoroalkyl ethoxymethacrylate polymer. Their low abrasion resistance and moderate self-cleaning effect are a disadvantage of such coatings.

The doctrine of EP 0 909 747 A1 is a process for producing a self-cleaning property of surfaces, in particular roof tiles. The surface has hydrophobic elevations with a height of

5 to 200 μm . Such a surface is produced by application of a dispersion of powder particles of an inert material in a siloxane solution and subsequent curing. As in the process acknowledged above, the structure-forming particles are not fixed on the surface of the substrate in an abrasion-stable manner.

- 5 The doctrine of EP Patent 0 772 514 is self-cleaning surfaces of objects with a synthetic surface structure of elevations and depressions, the distance between the elevations being in the range from 5 to 200 μm and the height of the elevations being in the range from 5 to 100 μm and the structure comprising hydrophobic polymers or materials which have been hydrophobized in a stable manner. Etching and embossing processes,
10 and furthermore coating processes are suitable for formation of the structures. If necessary, the formation of the structure is followed by a hydrophobization, for example a so-called silanization.

- Similarly structured surfaces with hydrophobic properties are the doctrine of EP 0 933 388 A2. The surface has elevations with an average height of 50 nm to 10 μm and an
15 average separation of between 50 nm to 10 μm , and a surface energy of the non-structured material of 10 to 20 mN/m. To achieve a particularly low surface energy and thus hydrophobic and oleophobic properties, the structured surface comprises fluorine-containing polymers or has been treated using alkylfluorosilanes. Indications of also using coating processes, instead of the shaping processes disclosed here, for structuring
20 the surface are not to be obtained from this document.

- The doctrine of DE Patent Application 100 16 485.4 is glass, ceramic and metal substrates with a self-cleaning surface based on a structured and at least partly hydrophobized coating. The coating comprises a glass flux and structure-forming particles with an average particle diameter in the range from 0.1 to 50 μm . The glass
25 flux and structure-forming particles are present in a volume ratio in the range from 0.1 to 5 and the micro-rough surface structure has a ratio of average profile height to average distance between adjacent profile peaks in the range from 0.3 to 10. The self-cleaning surface has a higher abrasion resistance than self-cleaning surfaces of roof tiles according to the EP 0 909 747 A1 acknowledged above.

- 30 The object of the invention is to provide substrates, in particular substrates of glass, ceramic, plastic and metal and glazed and enamelled substrates, with at least one self-cleaning surface which not only have a low roll-off angle or high contact angle and therefore a good self-cleaning effect, but furthermore are transparent. The self-cleaning surface should have a very high contact angle with respect to water, preferably a contact

angle of about/above 150°. The transparency of a transparent substrate, such as glass or plastic, should as far as possible not be reduced. A decoration under the self-cleaning surface should remain clearly detectable. According to a further object, glass, ceramic or metal substrates or glazed or enamelled substrates according to the invention should
5 have a higher abrasion resistance than substrates which are already known and on which the structured surface is made of an organic polymer or comprises structure-forming particles bonded in an organic polymeric material. According to a further object of the invention, the substrates with the self-cleaning surface according to the invention should be obtainable by means of a simple process, preferably by processes such as are used in
10 the glass and ceramics industry or metal-processing industry for decorating surfaces. These and further objects such as are deduced from the further description do not have to be achieved together in all the embodiments.

The invention accordingly provides a substrate, in particular a substrate of glass, ceramic, plastic and metal or a glazed or enamelled substrate, with at least one self-
15 cleaning surface, comprising a coating which is arranged on the substrate, comprises particles which form a surface structure and is at least partly superficially hydrophobic, which is characterized in that the structure-forming particles have an average diameter of less than 100 nm. The subclaims relate to preferred embodiments.

It has been found that substrates with a superficially hydrophobic coating with a
20 "nanoscale" surface structure have an outstanding self-cleaning effect if the coating comprises structure-forming particles with an average diameter of less than 100 nm. The particle diameter is preferably in the range from less than 50 nm to 5 nm. The term average diameter here is understood as meaning the diameter of primary particles, and not the diameter of agglomerates. In general, at least 90 % and preferably about 100 %
25 of the primary particles have a diameter of less than 100 nm and particularly preferably less than 50 nm. The term "nanoscale" means that the structure has considerably lower profile heights and distances between profile peaks – apart from in agglomerates these are smaller than the particle diameter – than surfaces with structure-forming particles in the micrometre range.

30 The structure-forming particles can be organic or inorganic substances. Examples of the inorganic substances which may be mentioned are: metal oxides, mixed oxides, silicates, sulfates, phosphates, borates, metal sulfides, oxosulfides, selenides and sulfoselenides, metal nitrides and oxide-nitrides and metal powders. Examples of the organic structure-forming particles which may be mentioned are carbon blacks and
35 nanoscale organic polymeric particles, and among these fluorine-containing polymers.

Many structure-forming particles with the particle diameter according to the claims, such as, in particular, 5 to less than 50 nm, are commercially obtainable. They can otherwise be obtained by precipitation processes which are known per se or by pyrogenic processes, gaseous starting substances being converted into pulverulent substances. The structure-forming particles are particularly preferably metal oxides from the series consisting of silica (SiO_2), titanium dioxide (TiO_2), aluminium oxide (Al_2O_3), zirconium dioxide (ZrO_2) and tin dioxide (SnO_2). These oxides are particularly preferably pyrogenically prepared oxides, and among these in particular silica. Pyrogenic silicas are commercially obtainable with an average primary particle size in the range from about 7 to 40 nm.

In addition to the structure-forming particles, the self-cleaning surface of substrates according to the invention comprises a layer-forming material, which can be an inorganic or organic material. The layer-forming material either forms a homogeneous layer in which the structure-forming particles are fixed in the form of their primary particles and/or agglomerates, or the structure-forming particles are fixed on the substrate by means of the layer-forming material. Some of the primary particles and/or agglomerates thereof project at least partly out of the surface and in this manner form elevations and depressions, which, in addition to the hydrophobization, are responsible for the effect according to the invention.

Among the layer-forming materials, inorganic materials are particularly preferred. The material is expediently a vitreous material. Such a material can have been formed in the context of ceramic firing from one or more glass frits or glass-forming raw materials. During the firing, the vitreous material encloses structure-forming particles such that some of these project out of the surface. The glass frits employed for the production of the self-cleaning surface according to the invention are those with a composition which has a melting point below that of the structure-forming particles and below the deformation temperature of the substrate to be coated.

According to an alternative embodiment, the vitreous material is a substance which, during firing from one or more glass-forming raw materials, in particular low-melting oxidic or sufficiently reactive raw materials, forms vitreous bonds with constituents of the substrate and/or some of the structure-forming particles. These bonds are structural elements of the general formula Me-O-Me' , wherein Me and Me' can be identical or different and represent boron, silicon, phosphorus, aluminium, titanium, tin, zirconium or other metals of the substrate.

An example of a material which contains Me-O-Me' structural elements and in which the structure-forming particles are embedded is a system such as is obtained, during firing carried out after coating, by coating glass or a vitreous or enamelled substrate with a composition comprising boric acid and/or an alkali metal phosphate and
5 structure-forming particles. The boric acid and/or the phosphate thus form a chemical bond to reactive groups of the glass substrate or the glazing/enamel layer and optionally additionally the structure-forming particles during the firing.

According to a further alternative, coating materials with Me-O-Me' structural elements are those systems such as are formed from organometallic compounds of the elements
10 boron, silicon, aluminium, titanium and zirconium which have at least two hydrolysable groupings during alcoholysis/hydrolysis with a subsequent condensation reaction and optionally subsequent firing.

According to a preferred embodiment of the substrate according to the invention with a self-cleaning surface, the structured coating comprises structure-forming particles with
15 an average diameter of less than 100 nm, in particular in the range from 5 nm to less than 50 nm, and a layer-forming inorganic or organic material in a weight ratio in the range from 100 : 1 to 1 : 2, in particular 20 : 1 to 1 : 1. A ratio outside the limits mentioned is indeed possible, but if the content of layer-forming material is too low, a possibly inadequate fixing of the structure-forming particles is the consequence. In the
20 case of too high a content of the layer-forming material, the self-cleaning effect decreases because the structure-forming particles may be sunk too low in the layer-forming material.

Preferred substrates have a coating which substantially comprises structure-forming particles and a layer-forming inorganic material, but the coating can additionally
25 comprise adhesion promoters or those compounds such as are formed from auxiliary substances present and/or precursors of the layer-forming material during the production of the coating, including a heat treatment step which may be necessary or firing.

In order to impart to the structured surface the necessary hydrophobic properties and
30 also the desired high contact angle, in particular about/above 150°, or low roll-off angle, in particular about/below 1°, there is on the structured layer as a rule a hydrophobic layer, for example one such as is obtained by silanization.

According to a further embodiment, the self-cleaning surface according to the invention also comprises, in addition to the nanoscale elevations and depressions produced by the structure-forming particles, an over-structure, elevations and depressions in regular or stochastic distribution forming a micro-rough structure. The term "micro-rough" means
5 a height of the profile peaks and a distance between the profile peaks in the range from 0.1 to 50 μm , in particular 0.5 to 15 μm . Such substrates according to the invention with a nanoscale and additionally a microscale surface roughness can have a single or two structure-forming coatings on the substrate, in the first case the nanoscale and microscale particles being distributed in a layer-forming material. In the second case
10 there is a coating with the nanoscale particles on a coating with the microscale particles which has been applied beforehand.

According to a particularly preferred embodiment, the substrate is a glass or an enamelled glass, the coating according to the invention to achieve the self-cleaning properties being substantially transparent.

15 Substrates according to the invention with a self-cleaning surface have a superficially hydrophobic coating. If the coating itself does not have hydrophobic properties, this property is effected by application of a substance having a hydrophobizing action to the structured surface. Organosilanes, and here in particular fluorine-containing organosilanes, are particularly expedient for the hydrophobization. If the coating
20 material of the structure-forming surface is a vitreous material, Si-O-Si structural elements can also be formed by using organosilanes having a hydrophobizing action, as a result of which the component having a hydrophobizing action is fixed firmly to the structured substrate and the self-cleaning properties thus remains [sic] permanently.

The invention furthermore relates to the process for the production of substrates
25 according to the invention and to compositions such as are used in the production thereof.

The compositions for the production of a substrate according to the invention with a self-cleaning surface are substance mixtures which comprise structure-forming particles with an average particle diameter of less than 100 nm, in particular particles with an
30 average particle diameter in the range from 5 nm to less than 50 nm, and a layer-forming particulate or liquid material. As mentioned above, the particle diameter is that of the primary particles and the diameter of at least 90 %, preferably substantially of all the particles, is preferably less than 100 nm, or less than 50 nm.

The layer-forming particulate or liquid material can be an organic or inorganic material. The term "layer-forming material" is understood as meaning a material which, in the context of application to the substrate by a physical or chemical route, is capable of forming a homogeneous layer and of fixing the structure-forming particles in the layer or/and on the substrate. If the material is an organic polymeric material or precursors of a polymer, this is present in the composition in the form of a solution in an organic or aqueous solvent or solvent mixture or in the form of an organic or aqueous suspension. The homogeneous layer is achieved by evaporation of the solvent and/or during a subsequent heat treatment by fusing together thermoplastic particles or by a condensation or polyaddition or polycondensation.

According to preferred embodiments of the composition, this comprises inorganic layer-forming materials or at least precursors thereof. Particularly suitable layer-forming organic materials are glass frits and oxidic raw materials (= precursors) which are capable of glass formation with other substances, such as, in particular, boric acid (B_2O_3), bismuth oxide (Bi_2O_3), alkali metal and alkaline earth metal oxides, zinc oxide and lead oxide as well as alkali metal silicates, and phosphates and borates. Most glass-forming substances are contained in the composition in particulate form. Alkali metal oxides and alkali metal silicates are expediently contained in the composition in the form of aqueous alkali solution or in the form of water-glass (sodium silicate solution).

According to a further alternative, the compositions according to the invention comprise an organometallic compound of one or more of the elements boron, silicon, aluminium, titanium and zirconium as the layer-forming material. The organometallic compounds are preferably those which contain alkoxy groups, acetyl groups or acetylacetonate groupings, so that Me-O-Me' structural elements are formed by a condensation reaction, wherein Me and Me' can be identical or different and represent the elements mentioned.

The structure-forming particles and the layer-forming material are usually contained in the composition according to the invention in a weight ratio of 100 : 1 to 1 : 2; the weight ratio is preferably in the range from 20 : 1 to 1 : 1.

Pulverulent compositions according to the invention can be applied to the substrate by dusting or by electrostatic coating.

A preferred embodiment of the composition according to the invention also comprises, in addition to the layer-forming materials and the structure-forming particles, a liquid medium. The consistency of such a composition can be in wide ranges, for example for

the purpose of application by spraying or dipping, a considerably lower viscosity is established than in the case of application of the composition by a conventional printing process. In the case of use of the composition by a printing process, for example a screen printing process, the consistency of the composition is preferably paste-like.

- 5 Particularly preferred compositions which are suitable for the formation of a structured surface of a substrate of glass, ceramic, metal or a glazed or enamelled substrate comprise, as the layer-forming material, one or more glass frits as the main component, the softening point of these being sufficiently below the deformation temperature of the substrate to be coated. If the composition comprises raw materials which are capable of
10 glass formation (= precursors), those substances which are capable of undergoing chemical bonding with one another and/or with structural elements of the substrate and/or structural elements of the nanoscale particles under conventional firing conditions are chosen. Boric acid and alkali metal phosphates are particularly suitable layer-forming materials or precursors thereof.
- 15 Using a liquid to paste-like composition which comprises boric acid or an alkali metal dihydrogen phosphate as the layer-forming material or precursor thereof and a pyrogenic oxide as the structure-forming material, a firmly adhering structured surface can be formed on glass which, after hydrophobization with an organosilane, in particular a fluorine-containing organosilane, leads to particularly good self-cleaning
20 properties. The contact angle of a glass coated in this way is above 150°.

The liquid medium can be an organic or organic-aqueous or aqueous medium, which can comprise processing auxiliaries, such as agents to adjust the viscosity, in addition to the obligatory components.

- The surface of the micro-rough layer is at least partly hydrophobized, in particular the
25 peaks and elevations. Preferably, however, the entire surface is hydrophobized. The hydrophobization substantially comprises a very thin coating, for example of a thickness of 1 to 10 nm, which adheres firmly to the underlying surface. This adhesion is effected by film formation of the coating composition after application. Preferred hydrophobizing agents are bonded chemically to the substrate, for example via an Si-O-Si bridge. Such bridges result from the reaction of a silanol group of a silicatic material
30 of the structured coating with an alkoxysilane or alkoxysiloxane. Preferred substrates according to the invention with a self-cleaning surface have a coating, often only a few atom layers thick, based on an alkyltrialkoxysilane and preferably a longer-chain fluoroalkyltrialkoxysilane or oligomers of these silanes.

The substrates according to the invention with a self-cleaning surface can be produced in a simple manner by a process which comprises the following steps:

1. coating of a surface of the substrate with a composition comprising structure-forming particles and an inorganic or organic layer-forming material, this composition being
5 pulverulent or, preferably, liquid to paste-like,
2. formation of a cohesive layer which fixes the structure-forming particles and adheres firmly to the substrate and
3. hydrophobization of the structured surface with a hydrophobizing agent, in particular an organosilane, which adheres firmly to the structured surface or forms a chemical
10 compound with this.

A particular feature of the process is the use of structure-forming particles with an average diameter of less than 100 nm, preferably less than 50 nm, and at least 5 nm. The profile heights of the elevations are, if no particles in the μm range which form an over-structure are present, less than 100 nm, in particular less than 50 nm. The structure-
15 forming particles and the layer-forming materials are those which have already been mentioned above.

The compositions to be applied by means of a conventional coating process preferably comprise the constituents essential to the invention, that is to say the structure-forming particles and the layer-forming material, in a ratio of amounts which has already been
20 mentioned above. If a pulverulent composition is used for the coating, this can be carried out by dusting the substrate or by electrostatic coating. The coating is preferably carried out using a liquid to paste-like composition, the liquid media contained in such a composition being those systems such as are known to the expert, in particular the decoration expert in the glass and ceramics industry. The coating with a liquid to paste-
25 like composition can be carried out by spraying, brushing, pouring or dipping or by means of a conventional printing process, such as a screen printing or a dabber transfer printing process.

The feature "formation of a cohesive layer which adheres firmly to the substrate and fixes the structure-forming particles" can vary according to the substrate to be coated
30 and the composition of the coating composition. If the composition comprises an organic polymeric material which is pulverulent or suspended in a liquid medium, a cohesive layer can be produced by passing the coated substrate to a heat treatment, solvent optionally present evaporating and polymer particles fusing together or, in the case of multi-component systems, reacting to give a polymeric material.

Compositions which are applied to a substrate which can undergo firing, that is to say a glass, ceramic or metal substrate or a glazed or enamelled substrate, and comprise a glass frit or constituents which are capable of glass formation with the substrate surface and/or the particles, can be converted into a cohesive structured layer by a heat
5 treatment, that is to say in this case firing. During firing, the glass frit melts to a homogeneous layer; the constituents of the composition which are capable of glass formation form [sic] a chemical reaction with reactive groups of the substrate and/or the structure-forming particles to form vitreous structures with structural elements of the formula Me-O-Me' , wherein Me and Me' have the meaning already given. The glass
10 frits and/or constituents capable of glass formation contained in the composition are chosen such that the heat treatment, that is to say the firing, can be carried out at a temperature below the deformation temperature of the substrate. In the coating of glass, the composition will accordingly comprise those layer-forming constituents which melt below 650 °C, in particular in the range from 450 to 600 °C and can form the required
15 structures.

The nanostructured coating to be applied to the substrate can have a varying layer thickness. Preferably, the layer thickness of layers which comprise as structure-forming particles exclusively particles according to the invention with an average diameter of less than 100 nm, in particular less than 50 nm, and at least 5 nm is in the range from 5
20 to 1000 nm. If the composition additionally comprises larger structure-forming particles, for example particles with a diameter in the range from 0.5 to 15 μm , the maximum height of the layer is of course higher. In the case mentioned last, the nanoscale structure according to the invention is on a micro-rough over-structure. Alternatively, it is also possible for a substrate with a micro-rough surface structure, for
25 example a surface structure such as substrates according to DE Patent Application 100 16 485.4 have, already to be coated with a composition according to the invention which comprises as structure-forming particles substantially only particles with a particle diameter of less than 100 nm, preferably less than 50 nm, to be baked and then to be hydrophobized.

30 After the formation of the structured surface, the hydrophobization stage follows:

The hydrophobization can be carried out by application of a hydrophobic lacquer or by polymerization of monomers on the micro-rough surface. Suitable polymeric lacquers are solutions or dispersions of e.g. polyvinylidene fluoride. A hydrophobization can also be carried out by plasma polymerization of completely or partly fluorinated vinyl
35 compounds.

The hydrophobization is particularly expediently carried out using reactive alkyl- or, preferably, fluoroalkylsilanes and oligomeric alkyl- or fluoroalkylsiloxanes. The silanes or siloxanes preferably contain one or more alkoxy or acetyl groups, such as ethoxy groups, as the reactive group. Crosslinking of the hydrophobizing agent and also
5 chemical bonding thereof to a silicatic surface containing silanol groups is possible by means of these functional groups. Silanizing agents which are particularly preferably to be used are tridecafluorooctyltriethoxysilane and oligomers thereof. Such products can be applied to the surface to be hydrophobized in the form of dilute organic, in particular alcoholic, aqueous-organic and aqueous solutions, for example by dipping, spraying or
10 brushing.

After application of a solution comprising a fluorine-containing silane or siloxane to the substrate, the substrate is dried and cured, preferably at a temperature of up to 500 °C, for example for 30-60 min at about 150 °C, 10-15 min at 250 to 300 °C or 1 min at about 500 °C. The optimum of the after-treatment with heat in respect of highest
15 abrasion resistance is at a temperature in the range from 200 to 300 °C.

Using dilute solutions of the silanes or siloxanes mentioned, layers a few nm thick which have a very high chemical and mechanical resistance and are 2- and 3-dimensional siloxane networks are obtained.

The hydrophobic layers accessible using reactive fluoroalkylsilanes or -siloxanes are
20 distinguished by a similarly good hydrophobicity and oleophobicity, so that substrates according to the invention contaminated with hydrophobic dirt particles can also easily be cleaned with water.

The invention also relates to the use of a substrate according to the invention with a self-cleaning surface. Examples are glass panes for vehicles and windows, construction
25 glass, ceramic tiles, roof tiles, covers on photovoltaic solar cells, metal profiles and lacquered substrates, such as car lacquers.

The substrates according to the invention with a self-cleaning surface are distinguished by a very high efficiency of the self-cleaning property. The contact angle of preferred substrates according to the invention with respect to water is in general about and often
30 above 150°.

A particularly outstanding feature of substrates according to the invention is the transparency of the nanostructured coating. Transparent substrates of plastic and glass and glazed or enamelled substrates are accordingly particularly suitable for being

provided with a transparent coating according to the invention and therefore for obtaining high-quality self-cleaning surfaces which are themselves transparent and therefore also clearly reveal underlying decorations.

Essential advantages of compositions according to the invention are their easy
5 accessibility and range of variation in respect of composition. The compositions can therefore be used for coating the most diverse substrates and producing good self-cleaning properties.

The stages of the process according to the invention are based closely on those process stages such as are used, for example, for decoration purposes in the glass and ceramics
10 industry, but are also conventional in the lacquering of metallic substrates with stoving lacquers. The devices and technologies known to the expert can therefore be used.

Examples

Production of float glass or high-grade steel with a transparent self-cleaning surface

1. 4 mm float glass was coated with a composition according to the invention by
15 means of screen printing. The composition comprised 0.5 wt.% boric acid (B_2O_3) and 4 wt.% pyrogenic silica in a screen printing medium (no. 80858 from dmc² AG). The pyrogenic silica had an average diameter of the primary particles of 12 nm. The printing medium was a water-friendly medium. The screen printing was carried out using a 100 T screen. After drying, the coating was shock-fired at 660°C
20 in the course of 4 min. The hydrophobization of the structured stoved surface was carried out using a fluoroalkylsilane formulation, that is to say an ethanolic solution of tridecafluorooctyltriethoxysilane. The solution was introduced over the surface, and curing was then carried out at elevated temperature.

25 The float glass coated in this way was transparent and had a contact angle of above 150°.

2. Example 1 was repeated with the only difference that the composition comprised 0.5
wt.% diammonium hydrogen phosphate $((NH)_2HPO_4)$ [sic] instead of boric acid as
the layer-forming material. After the hydrophobization, the glass coating showed
30 outstanding self-cleaning properties.

It is assumed that during firing vitreous structures with the structural element Si-O-

B or Si-O-P or metal-O-P form between the boric acid or the phosphate and reactive centres of the glass or metal and the structure-forming silica particles.

3. Substrate was degreased V4A high-grade steel. A composition with 4 wt.% pyrogenic silica ($d = 12$ nm) and diammonium hydrogen phosphate in an amount of (a) 0.25 wt.%, (b) 0.5 wt.% and (c) 1.0 wt.% in screen printing medium 80858 was used for the coating. After coating by means of screen printing, firing was carried out for 6 minutes at 660 °C. A scratch-resistant self-cleaning surface was obtained in all three cases.

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